International Conference on BEAM-SOLID INTERACTIONS

Middle East Technical University, Ankara

April 1989

ICBSI

Conference Program

DIRECTORS:

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- Turkish Physics Foundation

April 24, 1989 Monday

08:30	Registration	
09:30	Welcome (President of M.E.T.U.)	Ö. Saatçioğlu
09:40	Interdisciplinary Research - A U.K. Viewpoint	R.H. Williams
10:00	Cold Fusion in Italy	G. Benedek
10:30	Coffee/Tea	
11:00	Methods and Applications of Laser Chemical Processing for Microelectronics	D.J. Ehrlich
12:30	Lunch	
14:00	Photo-Engineering of Thin Film Structures	I.W. Boyd
14:45	Fundamental Mechanisms in Laser Assisted Evaporation	H. Sankur
15:30	Coffee/Tea	
16:00	Atom Beam - Surface Interactions	G. Benedek

April 25, 1989 Tuesday

09:00	Argon Laser Deposition of Microelectronic Materials	J.I.B. Wilson
10:30	Coffee/Tea	
11:00	Deposition of Dielectric and Semiconductor Thin Films by Laser Assisted Evaporation	H. Sankur
12:00	Laser Evaporation of some Metals and Compounds for Matrix Isolation Spectroscopy	Ş. Süzer
12:30	Lunch	
14:00	Photon-Beam Assisted Epitaxy of II-VI Semiconductors	J.F. Schetzina
15:30	Coffee/Tea	
16:00	Laser Processing of Semiconductors	A. Doi
16:45	Numerical Models in Laser Processing of Semiconductors	A. Aydınlı

April 26, 1989 Wednesday

09:00	Probing Semiconductor Interfaces by Photoemission and Raman Spectroscopies	R.H. Williams
10:30	Coffee/Tea	
11:00	Characterization of Laser Intermixed Superlattice Materials using Scanning Photoluminescence, Raman Spectroscopy and Auger Profiling	F.A. Chambers
12:30	Lunch	
14:00	City Sightseeing	

April 27, 1989 Thursday

09:00	Transport and Optical Properties of Layered Structure Semiconductors	J.H. Wolter
10:30	Coffee/Tea	
11:00	Photoconductivity in Quantum Wells	Ç. Arıkan
11:45	Tunneling Electron Beams for Analysis of Semiconductor Interfaces and Multilayers	H.W.M. Salemink
12:30	Lunch	
14:00	Use of Rutherford Backscattering and Channeling to Study Thin Epitaxial Layers of Semiconductors	E. Ligeon
15:30	Coffee/Tea	
16:00	Ion Implantation of Engineering Materials	S. Sarıtaş

April 28, 1989 Friday

09:00	Ion Beams as Tools for Materials Analysis and Modification	K. Bethge
10:30	Coffee/Tea	

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CONTENTS

I. INTRODUCTION

The International Conference on Beam-Solid Interactions was held at Middle East Technical University from April 24 to 28, 1989. There were sixteen invited speakers from USA (4), UK (3), France, the Netherlands, Germany, Switzerland, Hungary, Japan and from Turkey (3). On the average, more than fifty participants attended every conference talk.

After the welcome speach of Vice President Professor Muharrem Timuçin, Professor R.H. Williams of University of Wales, Cardiff, gave a talk on "Interdisciplinary Research - A UK Viewpoint". The second talk of the opening session, which attracted a crowd of audiance, was given by Professor G. Benedek of University of Milano, who reported on the dynamic Cold Fusion experiment with Ti and D_2 gas that was performed in Italy less than a week before then. The scientific sessions were divided into two main topics, namely, the interactions of laser beam and ion beam with solids. Both included talks on characterization as well as modifications of materials with beams. In addition, a talk on Inelastic Atom Beam Interaction with Solids and another one on Tunneling Electron Beams for Analysis of Semiconductor Interfaces and Multilayers were given by Prof. G. Benedek and Dr. H.W.M. Salemink, respectively. Some speakers well known in their fields were asked to include tutorial parts in their presentations, so that not only the graduate students in the audiance, but also the other participants including the lecturers of different disciplines would benefit from them. The conference was composed of talks, all being experimental in nature except one theoretical on Numerical Models in Laser Processing of Semiconductors by Prof. A. Aydınlı. The panel discussion was chaired by Prof. Bethge.

II. EVALUATION

The conference proceeded as planned with considerable success, in terms of both the quality of the presentations and the interactions between foreign and Turkish scientists. It also served as a means to introduce recent research to the interested audiance in Turkey. The allocation of tutorial parts by the key speakers in their lectures provided a relaxed and informative atmosphere, which generated much interest amoung young scientists. We would like to make a note of the positive and very encouraging comments of the invited speakers, namely the level and organization of the conference program and the interaction among the participants. The conference provided many new insights on the topics of beam-solid interactions and their importance in

the development of advanced technologies in microelectronics. Not only the participants but also the speakers stated that the conference material has been quite beneficial to them. We received encouragement to continue such international meetings in the future.

As a result of the satisfying and social atmosphere of the conference, there has been a number of support and collaboration offers by the foreign scientists. In particular the possibility of sending Turkish graduate students and postdocs to their laboratories, providing samples and assistance, and finally continuing contacts. The conference created enthusiasm also among visiting Turkish scientists for holding such meetings by themselves.

As a final comment, the late confirmation of some of the funds caused considerable delays in making the speakers list and following announcements. We are grateful to the speakers for their excellent preparations in spite of the short notices given to them.

III. FINANCIAL STATEMENT

Several financial sources were benefitted from for the organization of this conference. The contributions by the supporting organizations are listed below.

1. Middle East Technical University		
Lodging (4 persons)	850	
Transportation	550	
Printing and announcements	200	
Secretarial	300	
Cocktail	600	
TOTAL		$ 2,500
2. Bilkent University		
Lodging (12 persons)	2,500	
Transportation	350	
TOTAL		$ 2,850
3. Turkish Atomic Energy Authority		
Travel, lodging, meals for the Turkish participants		$ 1,000
4. British Council		
Travel for British lecturers		$ 1,450

5. International Center for Theoretical Physics

Travel for lecturers	$ 5,000

6. US Army Research and Development Standardization Group

Travel for Prof. D.J. Ehrlich	1,194	
Travel for Prof. J.E. Wolter	565	
Travel for Dr. E. Ligeon (GREN/PAR/GREN)	91	
Meals for the invited speakers	1,358	
Conference Picture (for all participants)	106	
Replacement of interface card	160	
Stationary and photocopy	275	
Postage (express)	72	
Miscelleneous	87	
Left in the account for further printing costs	92	
TOTAL		$ 4,000

7. Office of Naval Research European Office

Travel for lecturers, etc.	$ 4,500
GRAND TOTAL	$21,300

IV. CONFERENCE PROGRAM

The conference program is attached.

V. LIST OF SPEAKERS

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COLD NEUTRON FUSION IN ITALY

Giorgio Benedek

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ABSTRACT:

The recent reports by Fleischmann and Pons and by S. Jones of possible d-d fusion processes occurring in transition metal deuterides at ordinary temperatures have triggered also in Italy an enormous interest among nuclear, plasma and solid-state physicists, not to speak of electrochemists and energy engineers. Governmental and private research institutions have immediately started a race aimed at reproducing and improving those experiments. The official project established a few weeks ago at the national energy agency ENEA has already reached the astonishing result that cold fusion in titanium can be obtained by absorbing deuterium directly from the high-pressure gaseous phase, with no electrolyte nor electric currents. The neutron production was about 10^1 times the natural background, i.e., much larger than that found by S. Jones for titanium.

I will first report on the present experimental situation, with special attention to the seminar held on April 12 at Erice with the participation of Fleischmann, Jones and the best experts from USA, URRS and Europe. Then I will illustrate the state of the art in theoretical understanding of the possible processes at the nuclear and solid-state levels, with a brief account of the progress made in Milano.

A REVIEW OF LASER-MICROCHEMICAL PROCESSING [1]

D.J. Ehrlich and J.Y. Tsao

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Microfabrication processes based on focused-laser-beam activation of surface chemistry are reviewed with an emphasis on the classification of the diverse chemical processes used. Surface reactions are devided according to their method of activation and the material phase most important in the chemical kinetics. Examples of reaction mechanisms and means of confining reaction dimensions are given. New results demonstrating that linewidths for deposition and etching of Si can be $< 0.2\mu$m and $< 0.4\mu$m, respectively, are described. The ultimate limits to spatial resolution are explored in terms of an effective contrast (γ^*) for laser-microchemical processes. Enhanced diffusive transport, characteristic of laser microreactions, and its effect on ultimate reaction rates are also analyzed.

[1]This work was supported by the Defence Advanced Research Projects Agency, the Department of the Air Force, in part under a specific program sponsored by the Air Force Office of Scientific Research, and

PHOTO-ENGINEERING OF THIN FILM STRUCTURES

Ian W. Boyd

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ABSTRACT:

Photon beams can be used to induce a variety of physical and chemical reactions on many types of materials such as photolysis, pyrolysis, ablation, and annealing. These processes have been shown in recent years to be of potential use in microstructural engineering of advanced electronic and optoelectronic materials and devices[1].

This paper will briefly review the fundamental concepts involved in this regime of "Photo-Engineering", and the wide area encompassed by potential applications. More explicitly, recent applications of small volume and large area processing will be described. These involve the use of the cw Argon Ion laser to promote finely localised chemical changes to repair a proto-type VLSI chip, and the projection of a patterned Excimer laser beam to promote large area delineated oxide structures with features down to the micron level.

1. Ian W. Boyd, "Laser Processing of Thin Films and Micro-structures", Springer Series in Materials Science, Vol. 3, Springer-Verlag, Berlin, New York (1987), ISBN 0-387-17951-8.

FUNDAMENTAL MECHANISMS IN LASER ASSISTED EVAPORATION

Haluk Sankur

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ABSTRACT:

Laser assisted evaporation is an emerging thin film deposition technique which has several unique advantageous features. Congruent nature of the evaporation produces replication of the source stoichiometry in the films. Generation of energetic particles (e.g. fast ions) causes improved epitaxy in semiconductor films and dense, polycrystalline structures in dielectric films. Instantaneous nature of the evaporation and pulse to pulse reproducibility of the evaporation rate has led to very precise control of film composition and thickness and has resulted in significant achievements in "bandgap engineering" of semiconductor layers.

The underlying physical mechanisms of these features and their effect on thin film nucleation and growth will be discussed.

INELASTIC ATOM BEAM - SURFACE INTERACTION

Giorgio Benedek

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ABSTRACT:

The study of energy transfer in atom-surface collisions under rarified gas conditions, triggered by aerospace research and studies of heterogeneous catalysis, has led to the development of highly monochromatic atom beam sources. Intense nozzle beams of ^{4}He atoms with a velocity spread of less than 1% have been produced in the late seventies by J.P. Toennies in Göttingen. This breakthrough has paved the way to the spectroscopy of low-energy surface excitations, which has made a spectacular progress in the recent years.

Today He beams do for surface phonons the same job that cold neutron beams do for bulk phonons. However the interaction of atoms with solid surfaces is much more complex than the interaction of neutrons, and the determination of the surface phonon structure from He scattering requires a substantial theoretical analysis.

In this talk I will review the results obtained during the long-standing collaboration of our theoretical group in Milano with the experimental group of J.P. Toennies. First I will illustrate the experimental aspects of atom scattering; then I will overview a few theoretical concepts needed in the interpretation of inelastic scattering spectra. Finally I will present a few exemplary cases of what we have learnt about the surface dynamics of insulators, semiconductors and metals, and will discuss the implications, both in fundamental and applicative areas.

ARGON LASER DEPOSITION OF MICROELECTRONIC MATERIALS

J.I.B. Wilson

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ABSTRACT:

These two talks discuss the reasons for the widespread research interest in laser processing of materials, with particular reference to "direct writing" of structures by argon laser chemical vapour deposition. In view of the many specialist texts on this subject it could be inferred that the subject has reached maturity and is therefore appropriate for the commercial fabrication of microelectronic devices. Industry has not included in everyday production the many processes which have been demonstrated in the research laboratories. The reasons for this lack of interest are readily understood when silicon technology is involved, but there is more hope for new technologies to accept these new techniques. I describe some of the Heriot-Watt experiments on the deposition of silicon, silicon-carbon alloys, aliminium, gold and titanium and explain why we believe they are both interesting scientifically and useful technically.

DEPOSITION OF DIELECTRIC AND SEMICONDUCTOR FILMS BY LASER ASSISTED EVAPORATION

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ABSTRACT:

Laser assisted evaporation has been used to deposit dielectric, semiconductor and metal thin films. Some of the unique advantages of this technique have been realized in dielectric materials where hard, dense and polycrystalline layers with very good optical properties have been formed on ambient temperature substrates. High quality epitaxial CdTe and HgCdTe layers have also been grown with this technique, requiring lower substrate temperatures and on substrates and substrate orientations that are not amenable for crystalline growth by thermal evaporation. Superlattices of these materials are the first systems in the II-VI compounds to exhibit 2-D electron gas effect. Unique sawtooth superlattice structures have been grown proving the feasibility of very precise control that this technique offers.

Material and device properties as well recent work on superconducting and diamond like carbon films will be discussed.

LASER EVAPORATION OF SOME METALS AND COMPOUNDS FOR MATRIX ISOLATION SPECTROSCOPY

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ABSTRACT:

Lasers have established an indispensible corner in preparation of species which are difficult by conventional techniques. In this contribution, application of laser vaporization to some (i) metals, (ii) metal salts, (iii) some oxides, and (iv) graphite will be presented. The species formed are identified by Matrix Isolation UV-Visible and IR Spectroscopic techniques.

This work was carried out at the Chemistry Department of the University of Virginia, Charlottesville, VA, USA and is published in *J.Chem.Phys.* **89**, 5514(1988).

PHOTON BEAM ASSISTED EPITAXY OF II-VI SEMICONDUCTORS

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ABSTRACT:

Photoassisted molecular beam epitaxy, in which the substrate is illuminated during film growth, is being employed in a new approach to controlled substitutional doping of II-VI compound semiconductors. Substitutional doping of these materials has been a long standing problem which has severely limited their applications potential. The photoassisted MBE technique gives rise to dramatic changes in the electrical properties of as-grown epilayers. In particular, highly conducting n-type and p-type CdTe films have been grown using indium and antimony as n-type and p-type dopants, respectively. Double-crystal x-ray rocking curve data indicate that the doped epilayers are of high structural quality. Successful n-type doping of CdMnTe, a dilute magnetic semiconductor, with indium has also been achieved. More recently, photoassisted growth technique has been employed to prepare doped CdMnTe-CdTe quantum well structures and superlattices. We have also recently employed photoassisted molecular beam epitaxy to successfully prepare p-type and n-type modulation-doped HgCdTe. In this paper, we report details of the MBE growth experiments and describe the structural, optical and electrical properties that this new infrared quantum alloy of HgCdTe processes.

LASER PROCESSING OF SEMICONDUCTORS

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ABSTRACT:

Laser-controlled melting, etching, and deposition techniques are considered to be the most important candidate for the low temperature processing of semiconductor devices. This talk will address our new approaches in the laser deposition (photochemical effect) and the laser recrystallization (thermal effect).

As a demonstration of photochemical effect during argon ion laser irradiation, an analysis of laser metalorganic vapor phase epitaxy (Laser-MOVPE) of GaAs will be presented using a newly developed unified *growth model*[1] which has been proposed to explain various MOVPE techniques such as conventional MOVPE with and without laser irradiation[2], pulsed MOVPE[3], and laser ALE[3]. A comparison between the unified growth model and the experiments will be presented in detail. Surface reactions for trimethylgallium or triethylgallium adsorbed on the substrate surfaces are assumed to be the growth-rate-limiting steps. A catalytic effect is taken into account by assuming different decomposition rates for adsorbed alkyls on Ga- and As-terminated surfaces. The surface reactions are expressed in terms of reaction times and analyzed using a rate equation approach. Good agreement between experiments and calculations in all growth methods show the usefulness of the model.

As a demonstration of thermal effect during an argon ion laser irradiation, recrystallization of silicon-on-insulator structure will be presented using a new fabrication method[4] in which the conventional laser melting technique was combined with a liquid encapsulating technique. Substantial enlargement of the grain size is observed in Si films grown by the liquid encapsulated recrystallization (LER) method. The stabilization of the recrystallization process is likely due to features of the LER technique: i.e., effective heat release from the surface of molten Si, resulting in control of vertical temperature profile.

1. A. Doi, S. Iwai, T. Meguro, and S. Namba, *Jpn.J.Appl.Phys.* **27**, 795(1988).

2. Y. Aoyagi, S. Masuda, S. Namba, and A. Doi, *Appl.Phys.Lett.* **47**, 95(1985), [Errata; **48**, 378(1986)].

3. A. Doi, Y. Aoyagi, and S. Namba, *Appl.Phys.Lett.* **49**, 785(1986).

4. A. Doi, T. Asakawa, and S. Namba, *Jpn.J.Appl.Phys.* **28**, L128(1989).

NUMERICAL MODELS IN LASER IRRADIATION OF SEMICONDUCTORS

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ABSTRACT:

Recently much has been done in laser processing of semiconductor materials for various purposes. Many changes can occur in these materials when irradiated with cw and pulsed laser beams of various wavelengths. A fundamental aspect is the mathematical modeling of laser induced mechanisms, in particular heat and mass transport. Both spatial and temporal distribution of temperature and where applicable mass transported are sought after in order to understand the observed experimental data and predict new physical mechanisms that may be at work.

In this presentation, we review the work done on mathematical modeling of temperature rise and mass transport with particular attention to numerical calculations. While most of the data presented will be on silicon, it will be recognized that they are applicable to other semiconductors also, usually with minor modifications. Emphasis will be given to pulsed laser irradiation and explosive crystallization of amorphous silicon as well as its structural multilayers. Mass transport will focus on impurity redistribution and laser beam mixing of multilayers.

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PROBING SEMICONDUCTOR INTERFACES BY PHOTOEMISSION AND RAMAN SPECTROSCOPIES

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ABSTRACT:

Photon probes are used extensively to probe the electronic structure of solids. In particular photoelectron spectroscopy has been developed into one of the most powerful tools for probing band structures and chemical interactions at surfaces and interfaces. In this talk we discuss the basis of photoelectron spectroscopy and we describe the application to probe the physics of semiconductor interfaces. Some experiments on the use of Raman spectroscopy to probe heterojunction interfaces will also be discussed.

CHARACTERIZATION OF LASER INTERMIXED SUPERLATTICE MATERIALS USING SCANNING PHOTOLUMINESCENCE, RAMAN SPECTROSCOPY AND AUGER PROFILING

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The intermixing of quantum well structures and superlattice materials is an area of growing interest. The use of excimer lasers to accomplish intermixing is a promising technique. In this paper we describe an intermixing technique using a pulsed excimer laser and present several different types of characterization of intermixed regions. Raman spectroscopy is used to measure composition. Auger profiling data is used to evaluate the degree of intermixing and the depth of intermixing. A unique instrument, a scanning photoluminescence system, is used to characterize the spatial localization of the intermixed areas. A thermal melting model is used to qualitatively describe the results.

TRANSPORT AND OPTICAL PROPERTIES OF LAYERED SEMICONDUCTOR STRUCTURES

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ABSTRACT:

Research on layered epitaxial structures of semiconductor materials is a field of rapidly growing significance. Structures of special interest are the superlattice consisting of alternate ultra-thin layers of two dissimilar semiconductors, the quantum well formed by a thin semiconductor later sandwiched between two semiconductor layers with a larger bandgap, and the modulation-doped heterojunction. The controlled modification ('tailoring') of the energy-band structure gives some fascinating physical effects. There are also potential new applications, such as quantum-well lasers and high-electron-mobility transistors. Suitable growth technologies are metal-organic vapour-phase epitaxy (MO-VPE) and molecular beam epitaxy (MBE).

In this paper we first give a general overview of various aspects of the fundamental physics in these layers, the growth procedures and device applications. Then we focus on the transport properties of two-dimensional electron gases and carrier dynamics in quantum wells. In particular, we present recent results of measurements on magnetoquantum transport of two-dimensional electron gases including the Quantum Hall Effect. Finally, we discuss novel topographical techniques to profile the two-dimensional electron gas in GaAs/AlGaAs heterojunctions.

PHOTOCONDUCTIVITY IN QUANTUM WELLS

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ABSTRACT:

An investigation of photoconductivity as a result of the interaction of light with solids, in particular with semiconductors is outlined. The spectral dependence of in-plane photoconductivity in GaAs/GaAlAs quantum wells (QW's) is experimentally studied at different temperatures and conditions. Results are discussed and compared with a simple theory, based on an effective mass jumps between two different compositions, in a one dimensional QW problem which predicts the excitonic transitions in QW's.

In addition to the observed excitonic spectra, another structure is observed at low temperatures just below the energy gap of GaAs. This is discussed as a possible effect of deep donors in GaAlAs barrier material in QW's.

TUNNELING ELECTRON BEAMS FOR ANALYSIS OF SEMICONDUCTOR INTERFACES AND MULTILAYERS

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ABSTRACT:

Tunneling microscopy is a relatively new tool to study the electronic properties of surfaces at very high spatial resolution, employing electron tunneling from a localized emitter through a controlled vacuum gap. The inherently involved surface property is the electronic density, at the energy of the tunneling beam (typically several electron volts around the Fermi energy). In the ultimate case, atomic resolution is obtained by mapping the local charge density on individual surface atoms.

By collecting the tunneling current during a fast voltage sweep, a local spectrum of energy states around the fermi energy is sampled. This spectroscopy mode allows to obtain the position of energy levels (or density of states) at specific objects on the scanned surface. The local density of states on different surface atomic bonds and absorbates has been successfully demonstrated with this technique.

An analogous spectroscopy mode is used to characterize the electronic properties of artificially grown GaAs multilayers along the <001> growth direction. In particular, the potential distribution along a p-n junction and the valence band offset in a GaAs-AlGaAs material interface is studied. It is shown that electronic properties can be observed with sub-nanometer resolution in such interfaces. This technique can be applied to the electronic environment near defects and in interfaces, on cleaved cross-sections along the preferential GaAs growth direction.

ION BEAM ANALYSIS - RUTHERFORD BACKSCATTERING AND CHANNELING – APPLICATION TO EPITAXIAL LAYERS, SURFACES AND INTERFACES

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ABSTRACT:

Ion beam analysis is an accurate method to determine the composition depth profiles in thin layers. For monocrystalline material, for instance, epitaxial layers, the combination of Rutherford backscattering (R.B.S) and channeling plays an important role: Surface reconstruction, determination of interface defects, location of impurities in the lattice and, more generally, layer growth processes. These methods are illustrated by some examples in II-VI semiconductor characterization: strain and misfit dislocation measurements for CdTe/CdZnTe systems, depth composition and growth defects in very thin layers ($\sim 20\AA$), determination of the polarity and the bonding direction of atoms in the zinc-blende structure.

ION IMPLANTATION OF ENGINEERING MATERIALS

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ABSTRACT:

Ion implantation is the process of modifying the physical or chemical properties of the near surface of a solid by embedding appropriate atoms into it from a beam of ionized particals. The properties to be modified may be electrical, optical, mechanical, tribological or corrosion behaviour.

It is an entirely new method of metal finishing, distinct from that of ion plating, and not a coating technique. Element to be implanted is ionized in a source unit and then separated and accelerated through a voltage drop to impinge on the material at high velocity. Workpiece is located perpendicular to the direction of ion beams and it is in a moderately hard vacuum. The implanted species come to rest at a mean depth which depends on the conditions but is usually around 0.1 micrometer. Penetration is not dependent on the diffusion of atoms and therefore little influenced by crystal defects and oxide films.

The process is initially developed for semiconductor device processing, but now finds applications in surface finishing of metals and alloys. Many metals, alloys and other engineering materials have been ion implanted. Some of them are: Copper and copper alloys, various steels, cemented carbides, titanium and titanium alloys, aluminum and aluminum alloys, polymers and ceramics.

Although the implanted layer is very thin; remarkable improvements on wear, friction and corrosion resistance have been reported by many investigators. This paper briefly explains the ion implantation process and then reviews some of its applications on metals and alloys.

MEASUREMENT OF LASER PRODUCED PLASMA CHARACTERISTICS USING STREAK PHOTOGRAPHY TECHNIQUE

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ABSTRACT:

Lasers are considered as practical and economic tools for several industrial applications; i.e, cutting, drilling, welding etc. The power intensities of 10^{10}-10^{15} W/m^2 are required to generate the nonconduction limited heating, which is necessary for these processes. To achieve these power intensities, the laser beam must be focused down to a small area by a suitable lens; the radiant energy is then absorbed and converted to internal energy, and melting that the plasma formation developes, respectively.

In the present study, a streak camera was used to photograph the plasma created on the material surface; a number of measurements were carried out for different purposes. The measurements are concentrated on the effects of different gas pressures on the plasma plume first, and the effects on the machining in general, aiming also to compare these results with the results obtained previously.

A quantitative and qualitative measurement of the plasma plume size are presented, showing the plume behaviour during the pulse period.